Swimming depth of sea trout

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Swimming depth of sea trout

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Summary

Data on swimming depth of sea trout *Salmo trutta* (L.) in Icelandic waters was extracted and collated into a suitable format for use in marine renewables risk assessment. The data shows that the fish are close to the surface much of the time, with some time being spent at greater depths.

1. Introduction

The Scottish Government has a target for 100% of the Scottish demand for electricity to be met from renewable resources by 2020 by creating a balanced portfolio of both onshore and offshore technologies. To ensure that the developments are ecologically sustainable, there is a need for data on relevant ecological matters, including the behaviour of fish in the vicinity of proposed offshore developments. The recent Annex IV 2016 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World review (available at *http://tethys.pnnl.gov/sites/default/files/attachments/SoS-Report-Public_Review-Draft_highres.pdf*) points out that “the possibility of marine animals colliding with dynamic components of MRE (marine renewable energy) devices is the greatest challenge to siting and permitting”. While this concern is most strongly expressed in relation to marine mammals, similar risks apply to marine fish, for example diadromous species. These risks to fish species are partly dependent on their depth distribution at sea. Fish which predominantly occupy space close to the surface will be at less risk from bottom-mounted tidal turbines than fish that have a bentho-pelagic lifestyle.

The sea trout *Salmo trutta* (L.) is one of the fish species which occurs in areas with renewable energy potential, and it is of high conservation, commercial and recreational fishing importance. However, information on swimming depths of sea trout is scarce and not in a suitable format for direct incorporation into collision models for tidal turbines (see, for example Band [2015]), which require depth frequency information for different swimming depth bands. The need for information led to the author of this report being contracted by Marine Scotland to work on data he had collected in various studies on sea trout during their sea migration in Icelandic waters. The work consisted of compiling and analysing the raw data on swimming depth into a format suitable for use in risk assessments. The data presented give detailed insight into the observed main patterns in vertical distribution of sea trout.

2. Sampling methodology and data characteristics

2.1. Monitoring of migration behaviour and environment with data storage tags

The data used in this report are derived from work carried out by the author on sea trout in Icelandic waters in the period 1996-2008. The sampling of the electronic data storage tags followed a pre-programmed schedule. The tags logged information on the fish depth and ambient temperature in the sea and in the rivers before and after the sea migration. Some tags were equipped with salinity (conductivity) sensors enabling recording of this parameter. In addition, a few tags had sensors which measured the pitch and roll of the fish, although these data are not presented in this report. Data storage tags have to be retrieved in order to access the stored data. As the recaptures were mainly based on angling, only some of the tags were retrieved.

2.2. The sea trout and the study area

The sea trout studied were from two rivers in south east Iceland. These rivers, the Rivers Tungulaekur and Grenlaekur are well known for their strong sea trout stocks and are located in a part of Iceland where sea trout is the most abundant salmonid (Figs. 1 and 2). The rivers are mainly springfed and each of the rivers discharges at a mean rate of about 2 m^3s^{-1} during the summer. The River Tungulaekur runs into large glacial river (River Skafta) which has a mean discharge of about 120 m^3s^{-1} and the River Grenlaekur has a joint estuary with River Skafta. The section of Icelandic coast which is involved is unsheltered and there are extensive areas of sand which extend from coastal beaches well out to sea. Hydrographical data from the Marine Research Institute, Reykjavik, Iceland (http://www.hafro.is) shows that there is a thermocline in the area at approximately 20 m depth during summer 2 - 27 km from shore. The coastal area is influenced significantly for hundreds of kilometres along the coast by the massive inflow of fresh water from glacial rivers in the summer. It is therefore possible that in some areas the sea trout can experience low salinity close to shore without entering an estuary. There is some information on the prey of sea trout in this area. Sandeels are the predominant prey although herring is also important when available. The sea trout also eat smaller prey such as amphipods and polychaetes, but they are much less important quantitatively to the diet.

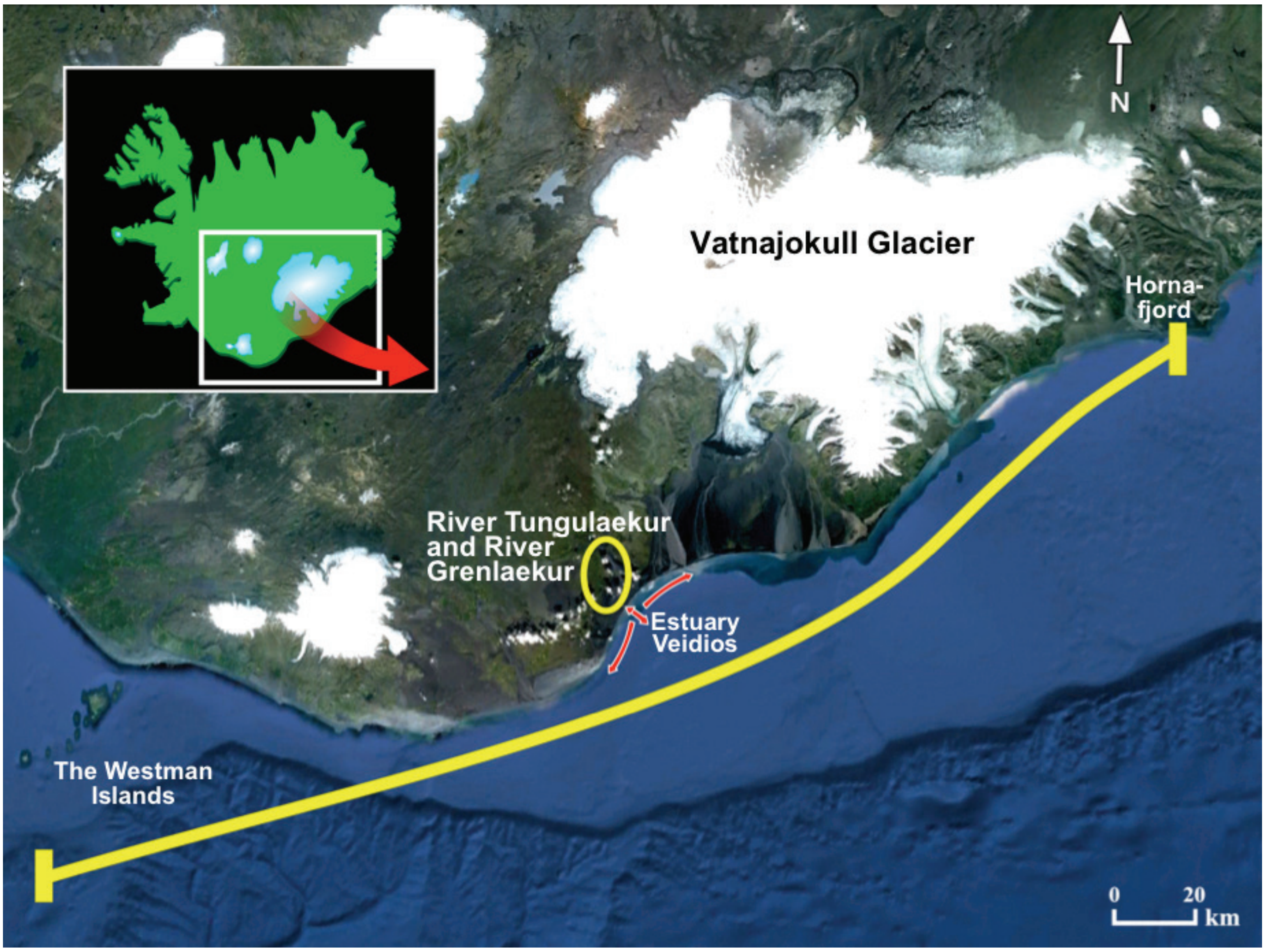


Fig. 1. Map of the coast of south Iceland, showing the area that the DST tagged sea trout are likely to have migrated through. The yellow circle shows the area where the two home rivers of the monitored sea trout are located (Tungulaekur and Grenlaekur). Also marked is the estuary Veidios where River Grenlaekur runs into sea as well as River Skafta, the glacial river which River Tungulaekur runs into. Red arrows indicate the feeding area of the sea trout closest to the estuary. The yellow line shows the coastal area that foraging sea trout from River Grenlaekur and River Tungulaekur utilise, from known outer limits of their distribution during sea migration (maximum of approximately 160 km east and west of Veidios) (Sturlaugsson, pers. observations).

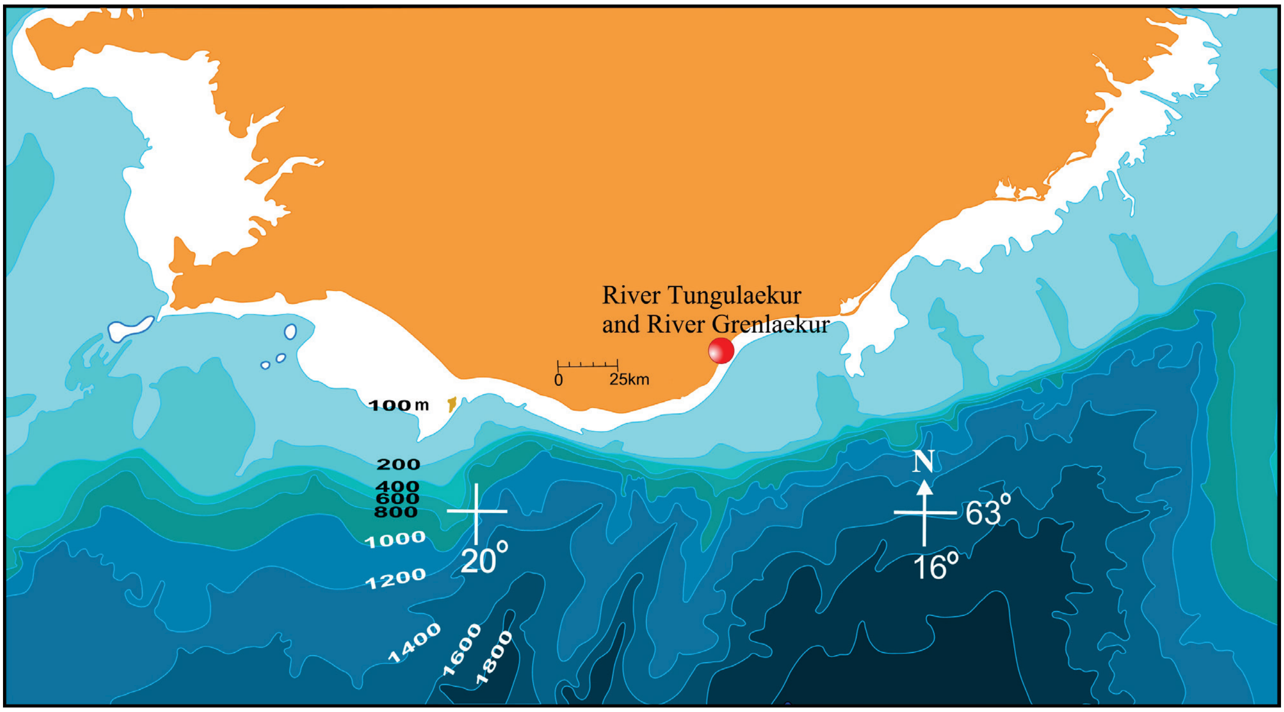


Fig. 2. Map of the coast of south Iceland, showing water depth intervals by bottom depth isolines (100m, 200m etc.). The waters are relatively shallow along the coast with water of depth 20 m or less extending 1-2 km out from shore. The area where the Rivers Tungulaekur and Grenlaekur are located is shown.

2.3. Data sampling

The sea trout were tagged in the rivers, and included both immature and mature fish. Most were captured by rod fishing and tagged and released the same day. The great majority of fish were tagged in the spring prior to their annual sea migration, although a few were tagged at their spawning grounds in the autumn. Most of the DSTs were attached externally using a modified Carlin method although, in a few instances, the DSTs were implanted into the peritoneal cavity.

The manufacturer's declared accuracy of depth measurements for the DSTs used in the studies was +/- 0.4% of selected depth range, which was 50 m. The accuracy of the temperature measurements was +/- 0.1°C and the accuracy of salinity measurements +/- 1 psu.

The sampling rate differed between and within years, depending on the tag memory, tag type and the aim of the particular study. The densest (highest frequency) measurements were collected over shorter periods within the summer, when recording intervals of up to 5-10 seconds were used to obtain more detailed information on the vertical distribution and on the actual swimming between depth layers. Table 1 lists the number of fish from which data were obtained for each of the eight years and the number of recordings for corresponding measuring intervals. Table 2 gives the periods in each of these years when subsampling was carried out.

Table 1. Measurement intervals of DSTs used in given year are shown for 1996-2008. For the intervals involved in each year the number of fish that carried the tags during their sea migration and the number of recordings sampled from the sea migrations are given.

		Measurement Interval										
Year	**Number of Fish and Recordings**	**5 sec**	**10 sec**	**30 sec**	**1 min**	**5 min**	**10 min**	**20 min**	**30 min**	**1 hour**	**2 hours**	**Records - Grand Total**
1996	N-Fish							14		14		
	N-records							8,060		18,228		26,288
1997	N-Fish						10				10	
	N-records						2,890				6,878	9,768
1998	N-Fish								4		5	
	N-records								4,670		3,123	7,793
1999	N-Fish								7			
	N-records								19,676			19,676
2004	N-Fish	1	1			1						
	N-records	34,562	17,282			19,262						71,106
2006	N-Fish			2						2		
	N-records			5,762						2,925		8,687
2007	N-Fish	1									2	
	N-records	28,027									1,107	29,134
2008	N-Fish				3				3			
	N-records				17,284				7,476			24,760
Total Records		**62,589**	**17,282**	**5,762**	**17,284**	**19,262**	**2,890**	**8,060**	**31,822**	**21,153**	**11,108**	**197,212**

Table 2. Periods of subsampling during sea trout sea migration in the given year are shown for 1996-2008 for the relevant measuring interval.

	Measuring Periods of Sub-Sampling Shown for Corresponding Measurement Interval							
Year	**5 sec**	**10 sec**	**30 sec**	**1 min**	**5 min**	**10 min**	**20 min**	**30 min**
1996							May: 24-26; 31 June: 1-2; 7-9; 14-16; 21-23; 28-30 July : 5-7; 12-14; 19-21; 26-28 August: 2-4; 9-11; 16-18; 23-25; 30-31 September: 1	
1997						June: 25-27		
1998								July: 4-28
1999								
2004	June: 8 & 20	July: 2 & 14						
2006			June: 20 July: 21					
2007	June: 20 July: 11							
2008				June: 18-20 July: 1-3				

3. Processing and presentation of data

The results presented are based on DST data in which the whole sea migration was recorded from the home estuary to the sea feeding grounds and back into the home estuary when they entered the river prior to spawning and/or overwintering. The main patterns presented on the migration behaviour are based on uniform sampling throughout the whole sea migration. The results from the subsampling periods are also presented for comparison in relation to the overall depth distribution of the sea trout, to give extra insight into behaviour and to check whether the sampling rates may have influenced various aspects of the results.

The aim of the data analysis was to identify the major patterns in vertical distribution of sea trout. The main task was to compile the data in a way that gave a clear picture on how much time the sea trout spent within any given depth zone. That task was possible to implement comprehensively because of the large number of recordings on the monitored fish and the repeated monitoring in different years.

In addition to the presentation of the main patterns of distribution, detailed data on the variation found within the data sets are also presented. This was carried out in various ways. Firstly, by graphs showing how the individual depth of the sea trout varied with time and habitats, in some instances using the corresponding measurements of temperature and salinity. Secondly, the overall mean fish depth and corresponding confidence limits are presented for all the individuals used in the data processing of sea trout swimming depth. The possible variation of sea trout swimming depth in relation to light levels according to the sun position (day vs. dusk/dawn vs. darkness) is also explored. Following that, I examine, on a weekly basis, whether the swimming depth changes during the sea migration period and to what extent. For this purpose, I use data from 1997. That year, salinity was also measured which gives in parallel the opportunity to view by the same weekly means the variation in salinity as well as temperature experienced by the sea trout throughout the sea migration. Then the difference in salinity and temperature experienced by sea trout in 1997, within the given depth zones is presented. The final step in examining the data was to look at the data collected in 2004 when measurements were taken at 5 seconds interval.

4. Results

One matter to consider when drawing conclusions is the characteristics of the fish within a particular stock. The main information on the monitored sea trout is put forward in Tables 2 and 3. The length distribution was 32-76 cm at tagging and 47-81 cm at recapture (Table 1). The sea trout age at tagging ranged from 4-10 years. The life history based on scale readings of the tagged fish reflected the typical pattern in sea trout life in the local area. The sea trout spent 2-5 years in the river before their first sea migration. They then migrated every year into the sea and instances of up to six sea migrations were observed.

Table 3. The sea trout monitored during 1996-2008 listed by their reference number and the year of sea migration. When available the sex of the fish is given and their size and condition factor both at tagging and recapture. Information from scale readings on their life history is also presented: age, maturation history, age at first sea migration (smolt age) and history of earlier sea migrations.

Fish	Sea migr.	Sex	Length of Fish At tagging = L1 At recapture = L2		Weight of Fish At tagging = W1 At recapture = W2		Condition Factor At tagging = K1 At recapture = K2		Life history Information Prior to the recorded sea migration (information from scales)				
	Year		**L1**	**L2**	**W1**	**W2**	**K1**	**K2**	**Age**	**Maturity**	**Prior Spawning**	**Smolt Age**	**Prior Sea Migration**
(no.)		Male= 1 Female=2	(cm)	(cm)	(g)	(g)	(K)	(K)	(year)	Immature=0 Mature=1	(number)	(year)	(number)
1	1996		42.4	47.1	830	1020	1.09	0.98	6	0		5	1
2	1996		44.9		1060		1.17		5	0		3	2
3	1996		46.2	50.0	1150	1300	1.17	1.04	5	0		3	2
4	1996	2	46.8	52.0	1260	1500	1.23	1.07	5	0		3	2
5	1996	1	47.4	54.0	1020	1704	0.96	1.08	5	0		3	2
6	1996	2	49.6	54.8	1340	1870	1.10	1.14	5	0		3	2
7	1996	1	51.7	62.2	1520	2590	1.10	1.08		0			
8	1996	1	53.5	62.6	1570	2550	1.03	1.04	6	1		3	3
9	1996		55.5		1550	1700	0.91			1	1		
10	1996	1	56.4	60.0	1720	2800	0.96	1.30	6	1	1	3	3
11	1996	1	56.1	64.0	1940	2750	1.10	1.05	5	1	1	2	3
12	1996	1	56.3	62.0	1910	2400	1.07	1.01		1			
13	1996	2	60.4	62.9	1950	2753	0.88	1.11	8	1	3	3	5
14	1996	1	67.5	71.6	3190	3780	1.04	1.03	8	1	1	4	4
15	1997	1	44.5	48.1	960	1100	1.09	0.99	4	0	0	3	1
16	1997	2	51.8	56.9	1620	2020	1.17	1.10	5	0	0	3	2
17	1997	1	53.7	60.0	1820	2110	1.18	0.98	5	0	0	3	2
18	1997	2	55.6	60.0	1830	2500	1.06	1.16	6	0	0	3	3
19	1997	1	57.5	62.1	2340	2700	1.23	1.13	7	0	0	5	2
20	1997	2	54.4	58.0	1390	2100	0.86	1.08	6	1	1	3	3

21	1997	2	57.3	64.0	1650	3000	0.88	1.14	7	1	1	3	4
22	1997	2	59.0	61.3	1990	2240	0.97	0.97	8	1	2	4	4
23	1997	1	64.5	69.5	2780	3250	1.04	0.97	7	1	1	4	3
24	1997	2	68.8	70.0	2910	4000	0.89	1.17	10	1	3	4	6
25	1998	2	32.0	50.0	340	1550	1.04	1.24	4	0		3	1
26	1998	2	49.6	66.0	1400	3000	1.15	1.04	5	0		3	2
27	1998	1	66.3	69.0	2860	3900	0.98	1.19	7	1	2	3	4
28	1998	2	69.5	74.0	2840	4200	0.85	1.04		1			
29	1998	1	71.9	76.0	4050	5000	1.09	1.14	7	1	2	3	4
30	1999	2	49.0	54.0	1500	1995	1.27	1.27		0			
31	1999	1	53.6	58.0	1600	2200	1.04	1.13	7	0		4	3
32	1999	1	54.4	56.5	1890	2000	1.17	1.11		0			
33	1999	1	57.6	65.0	2140	3050	1.12	1.11	7	1	1	4	3
34	1999	1	60.6	66.0	2210	3000	0.99	1.04		1			
35	1999		62.3	64.7	2600	3520	1.08	1.30		1			
36	1999	1	73.8	78.0	4100	6100	1.02	1.29	7	1	2	3	4
37	2004	1	66.0	70.0	2911	5000	1.01	1.46	6	1	1	3	3
38[a)]	2006	2	58.8	68.0	2495	3165	1.23	1.01	6	1	1	3	3
39	2006	1	59.0	64.8	2252	2600	1.10	0.96	7	1	1	4	3
38[a)]	2007	2	[a)]	68.0	[a)]	3165			7	1	2	3	4
39[b)]	2007	1	72.7	76.5	3290	4390	0.86	0.98	7	1	2	3	4
39[b)]	2008	1	76.5	77.8	3625	3840	0.81	0.82	8	1	3	3	5
38[a)]	2008	2	68.0	69.0	2400	3130	0.76	0.95	8	1	3	3	5
40	2008	1	76.2	81.3	4005	4345	0.91	0.81	7	1	2	2	5

[a)] Sea migration of Fish no. 38 was monitored for 3 years: 2006 (not recaptured); 2007 (recaptured); 2008 (tagged again in spring, recaptured)

[b)] Sea migration of Fish no. 39 was monitored for 2 years: 2006 (recaptured); 2007 (tagged again in spring, recaptured)

Table 4. The sea trout monitored during 1996-2008 listed by their reference number and the year of sea migration together with time of tagging, sea entry, river entry and information on the duration of the sea migration. Recapture time is given and the number of measurements derived from the densest uniform measuring interval covering the sea migration of all fish in the given year.

Fish	Sea Migration	Tagging Time	Sea Migration Duration				Recapture Time	
Number	Year	Date	Sea Entry	River Entry	Duration		Fish Recaptured /Tag Retrieved	Uniform Measurements throughout Sea Migration
(no.)		(year day.month)	(day.month)	(day.month)	(hrs)	(days)	(year-season)	(no.)
1	1996	1996 5.5	7/8	2/9	632	26	1997-Spring	632
2	1996	1996 20.4	26/5	16/8	1983	83	1996-Summer	1,983
3	1996	1996 5.5	24/6	17/7	545	23	1996-Summer	545
4	1996	1996 20.4	3/6	20/7	1127	47	1996-Autumn	1,127
5	1996	1996 5.5	6/7	2/9	1400	58	1997-Spring	1,400
6	1996	1996 5.5	1/6	17/7	1109	46	1996-Summer	1,109
7	1996	1996 5.5	1/6	21/7	1193	50	1996-Autumn	1,193
8	1996	1996 4.5	4/6	17/8	1787	74	1997-Spring	1,787
9	1996	1996 4.5	24/5	22/7	1421	59	1997-Spring	1,421
10	1996	1996 20.4	22/5	23/7	1483	62	1996-Summer	1,483
11	1996	1996 20.4	31/5	18/7	1148	48	1996-Autumn	1,148
12	1996	1996 4.5	4/6	17/7	1045	44	1996-Autumn	1,045
13	1996	1996 20.4	1/6	12/7	999	42	1996-Summer	999
14	1996	1996 4.5	26/5	1/9	2356	98	1997-Summer	2,356
15	1997	1997 27.4	19/6	9/8	619	52	1998-Spring	619
16	1997	1997 26.4	29/5	19/7	610	51	1997-Autumn	610
17	1997	1997 26.4	31/5	21/7	606	51	1998-Spring	606
18	1997	1997 26.4	10/6	19/7	478	40	1997-Summer	478
19	1997	1997 27.4	10/6	21/7	499	42	1997-Summer	499
20	1997	1997 26.4	31/5	30/7	727	61	1997-Autumn	727

21	1997	1997	26.4	17/5	29/7	877	73	1997-Summer	877
22	1997	1997	26.4	17/5	20/7	772	64	1997-Autumn	772
23	1997	1997	26.4	17/5	11/8	1034	86	1998-Summer	1,034
24	1997	1997	26.4	31/5	24/7	656	55	1997-Summer	656
25	1998	1998	2.5	6/6	22/8	926	77	2000-Spring	926
26	1998	1998	3.5	5/6	26/7	613	51	2000-Summer	613
27	1998	1998	2.5	24/6	11/8	576	48	1998-Autumn	576
28	1998	1998	2.5	24/6	11/8	575	48	1998-Summer	575
29	1998	1998	3.5	24/6	30/7	433	36	2000-Summer	433
30	1999	1999	1.5	29/5	11/8	3586	75	1999-Summer	35,869
31	1999	1999	1.5	12/6	29/7	2251	47	1999-Summer	2,251
32	1999	1999	1.5	12/6	30/7	2276	47	1999-Summer	2,276
33	1999	1999	1.5	12/6	13/8	2976	62	1999-Summer	2,976
34	1999	1999	1.5	23/5	6/8	3633	76	1999-Summer	3,633
35	1999	1999	1.5	1/6	24/7	2581	54	2000-Spring	2,581
36	1999	1999	2.5	12/6	31/7	2373	49	1999-Summer	2,373
37	2004	2004	24.4	28/5	3/8	19262	67	2004-Autumn	19,262
38[a)]	2006	2005	2.10	1/6	1/8	1460	61	2007-Autumn	1,460
39	2006	2005	2.10	5/6	5/8	1465	61	2006-Autumn	1,465
38[a)]	2007	2005	2.10	30/5	25/7	674	56	2007-Autumn	674
39[b)]	2007	2007	2.4	5/6	11/7	433	36	2008-Winter	433
39[b)]	2008	2008	13.5	1/6	13/7	2013	42	2008-Winter	2,013
38[a)]	2008	2008	13.5	23/5	29/6	1776	37	2008-Summer	1,776
40	2008	2008	13.5	4/6	20/8	3687	77	2009-Winter	3,687

[a)] Sea migration of Fish no. 38 was monitored for 3 years: 2006 (not recaptured); 2007 (recaptured); 2008 (tagged again in Spring, recaptured)

[b)] Sea migration of Fish no. 39 was monitored for 2 years: 2006 (recaptured); 2007 (tagged again in Spring, recaptured)

Based on the life history data determined from scale reading, it was shown that the sea trout first spawned after the second or, more commonly, the third sea migration and then each year following sea migration. Back calculation of length from scales showed that most of the sea trout were 20-30 cm long when starting their first sea migration.

The period in which sea migrations of sea trout took place in 1996-2008 (Figure 3) shows that the main foraging of sea trout takes place in June and July although the first ones are already feeding at sea in May and the last ones are finishing their feeding migration in September. The main sea migration period corresponds closely with the non-darkness period from May 20 to July 23.

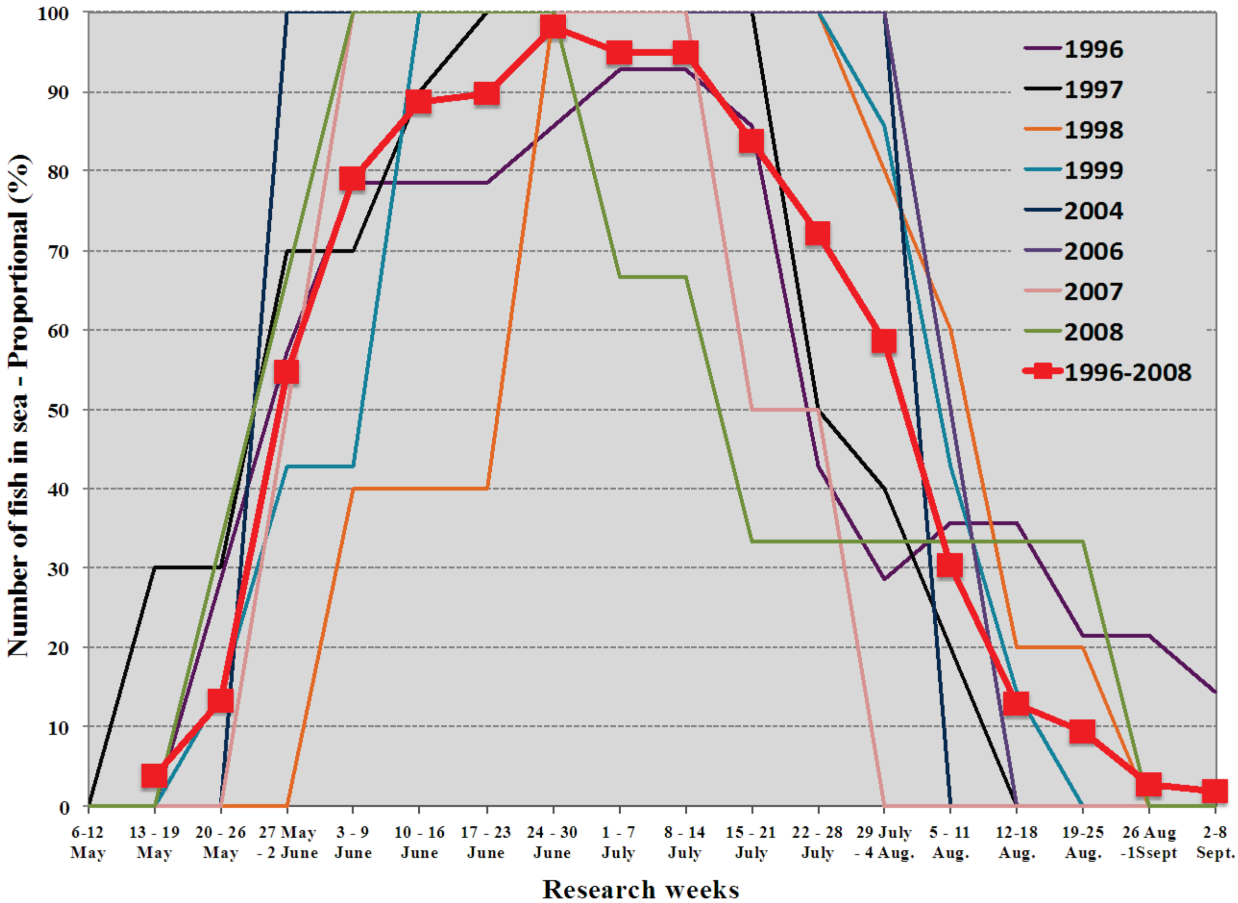


Fig. 3. The time sea trout spent at sea by research week as a proportion of the overall stay of all sea trout monitored throughout their sea migration with DSTs in each year. The mean proportional stay for each year is also given.

The similar sea migration duration of the same fish monitored for 2 and 3 sea migrations (Table 4) shows how uniform the sea migration of individuals can be between years.

In Figs. 4-7, examples of depth profiles from recordings throughout sea migration of four sea trout are shown, together with data from their migration in fresh water before and following their sea journey. The data demonstrate the pelagic behaviour of the sea trout during their sea migration. The temperature and salinity recordings show that the feeding migrations are shoreline orientated. This is shown by the rather frequent and brief deviations in temperature and salinity. These reflect the movements into low salinity warmer sea water close to the shore where the large inflow of fresh water from glacial rivers creates these conditions.

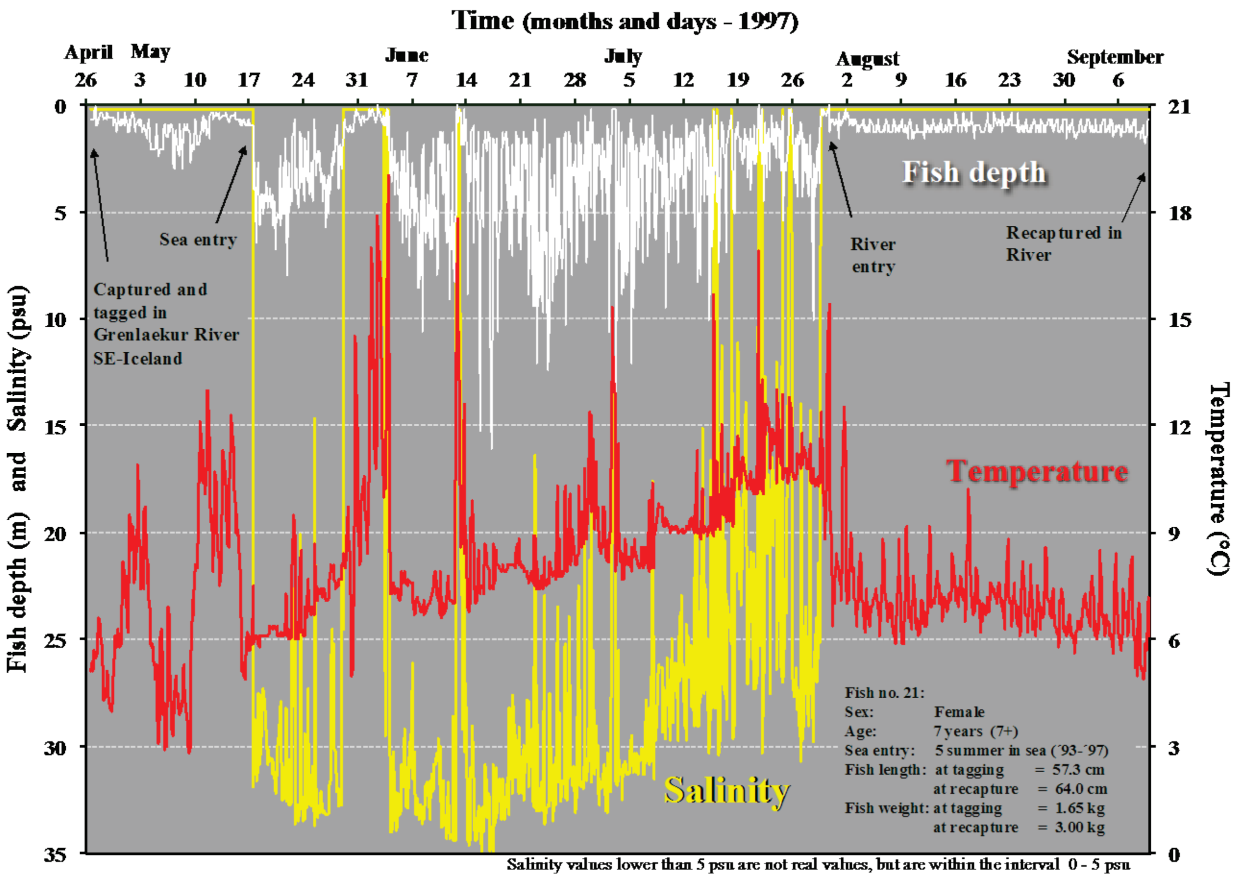


Fig. 4. Migratory pattern of sea trout during sea (feeding) migration and river migration. The depth distribution of the fish and corresponding ambient temperature and salinity in relation to time are shown.

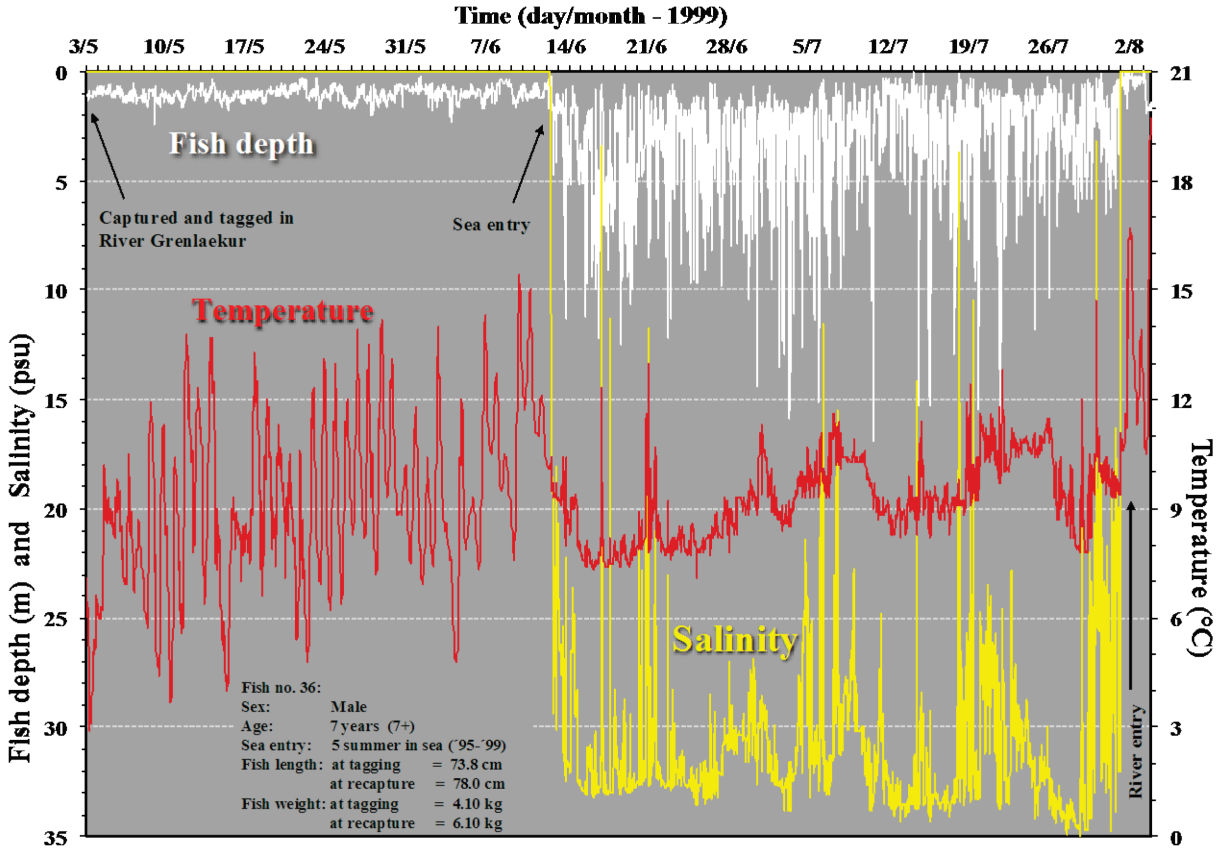
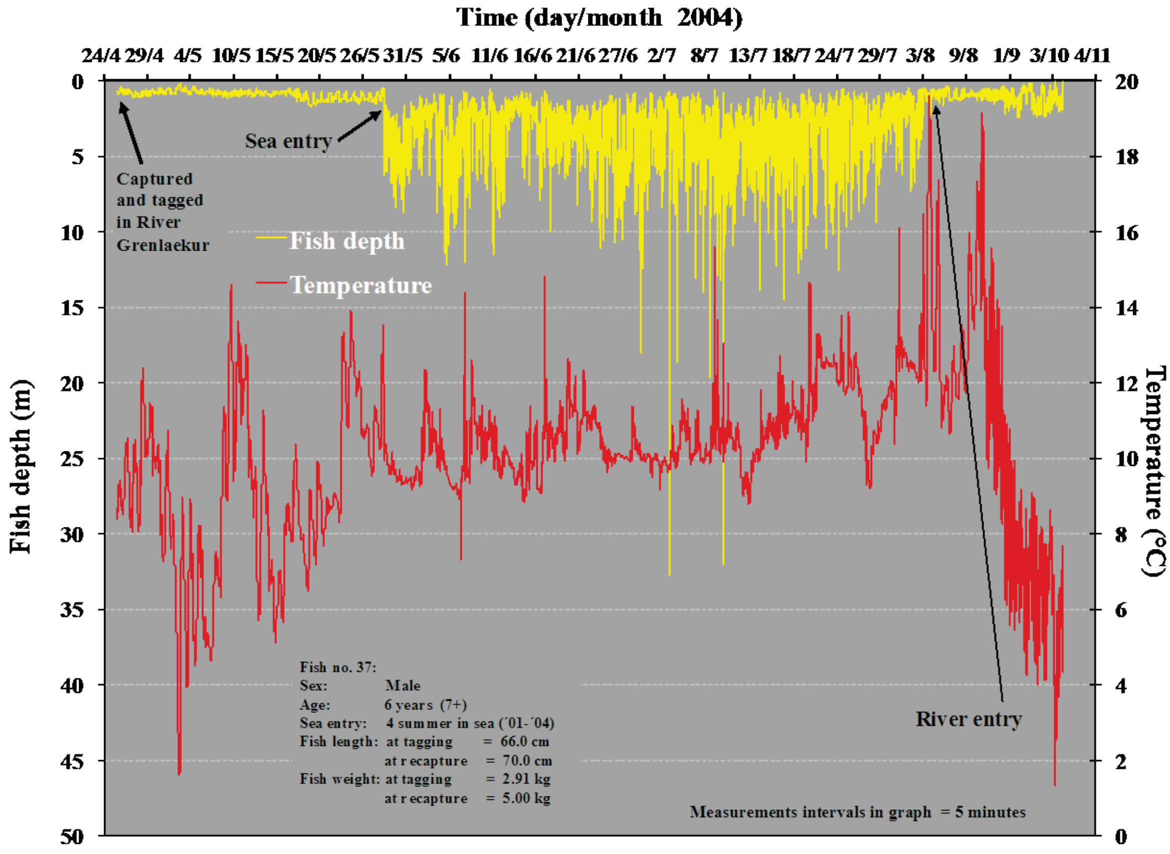
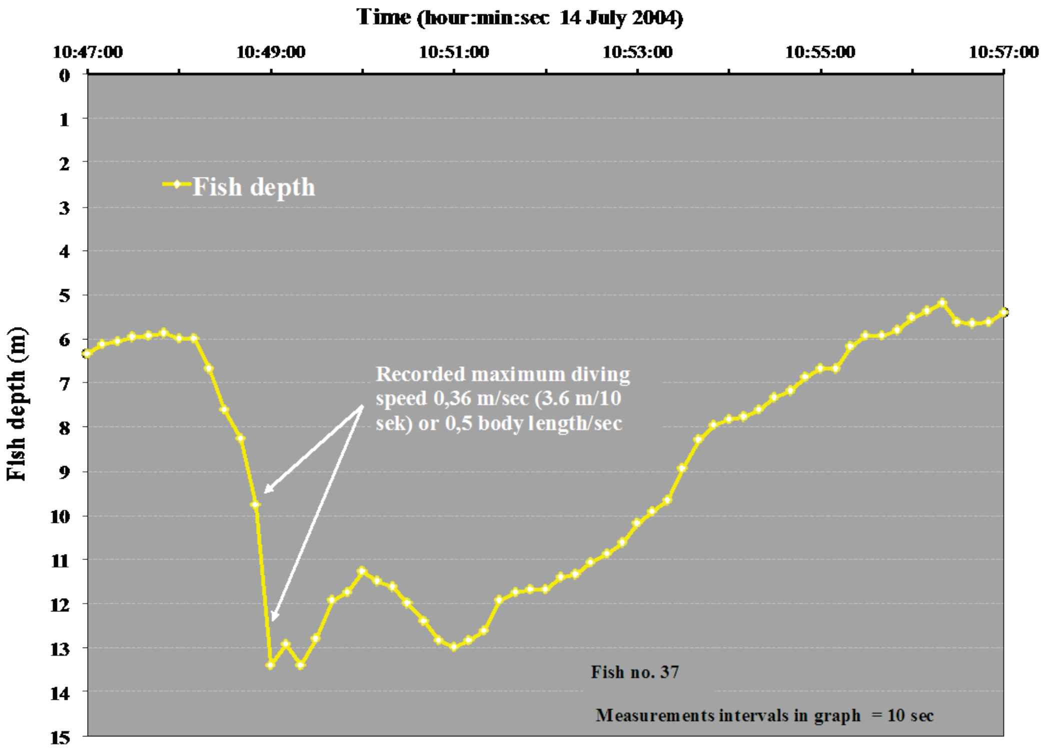


Fig. 5. Migratory pattern of sea trout during sea (feeding) migration and river migration. The depth distribution of the fish and corresponding ambient temperature and salinity in relation to time are shown.



A.



B.

Fig. 6. Migratory pattern of a sea trout during sea (feeding) migration and river migration. Depth distribution of the fish and corresponding ambient temperature in relation to time are shown in A and the behaviour of the fish is examined in more detail in B.

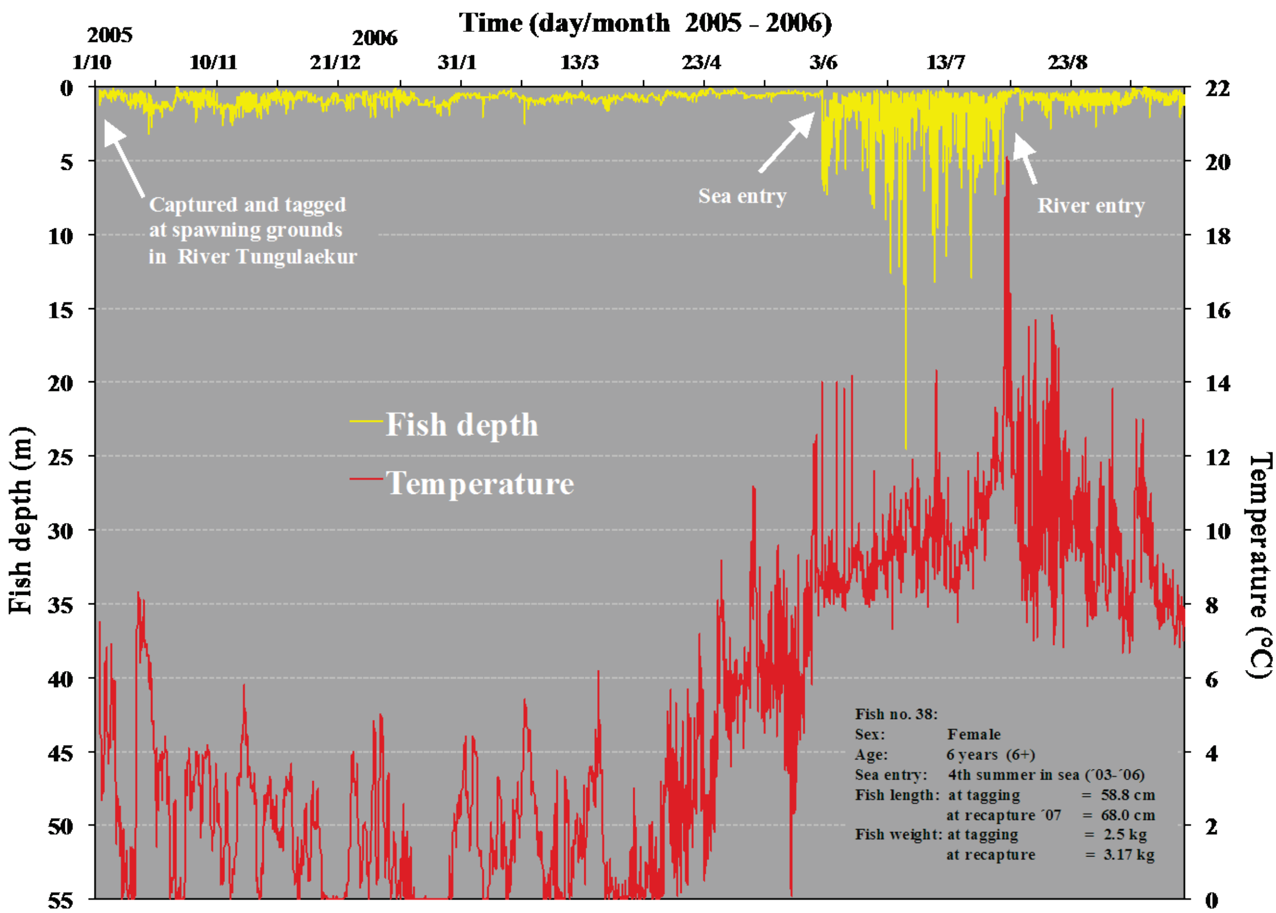


Fig. 7. Migratory pattern of sea trout during sea (feeding) migration and river migration. The depth distribution of the fish and corresponding ambient temperature are shown in relation to time.

The overall mean depths occupied by all the sea trout in any given year were calculated (Table 5). The results show that sea trout mainly stay just below the sea surface. In shallow water, they could of course also be close to the sea bottom at the same time. Some depth profiles from rapid sampling indicate periods of feeding up from bottom but the opposite, feeding down from surface layers, is also observed.

In Figure 8, the mean values for the overall depth of sea trout in sea is shown for every sampling year during the period 1996-2008 with 95% confidence limits. The variation is significant between some of the years although the absolute difference is small. Table 6 (and Fig. 9) show, for each sampling year, the proportion of the overall time spent within given 5m depth intervals, with the means for all fish across all years included in Table 6. Table 7 shows the mean depth within the 5 m depth intervals, given along with standard deviation for the eight sampling years, and again includes the means for all fish across all years.

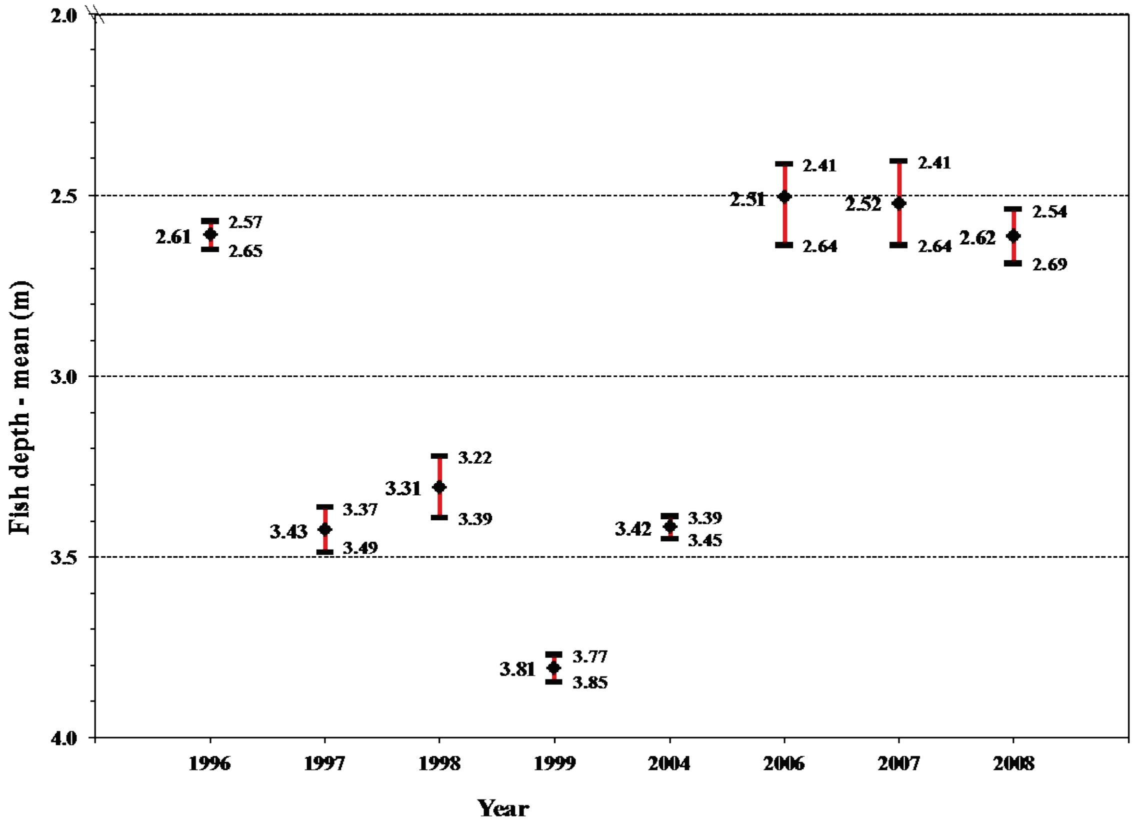


Fig. 8. Mean values for the overall mean fish depth with 95% confidence limits for each of the years sea trout were monitored with data storage tags during sea migration. The numerical values of the means and the corresponding lower and upper bounds of the 95% confidence intervals are shown.

Table 5. Overall mean depth of sea trout for every year within the period 1996-2008. The mean standard deviation is shown and the maximum depth recorded. The number of fish behind the recordings in sea each is also given along with the recording interval that covered the total sea migration and the total number of recordings behind the mean depth.

Year	**Fish Depth (Based on Uniform Measurements throughout the Sea Migration)**			**Fish Number Monitored during Sea Migration**	**Recording Interval Covering the whole Sea Migration and Corresponding Number of Rec.**	
	Mean	SD	Max	(no.)	Intervals	(no.)
1996	2.6	2.73	46.5	14	1 hour	18,228
1997	3.4	2.60	21.5	10	2 hours	6,878
1998	3.3	2.41	17.0	5	2 hours	3,123
1999	3.8	2.59	26.9	7	30 min	19,676
2004	3.4	2.11	32.8	1	5 min	19,262
2006	2.5	2.57	45.2	2	1 hour	2,925
2007	2.5	1.97	13.4	2	2 hours	1,107
2008	2.6	3.25	38.3	3	30 min	7,476
	Sea migration monitored - Total =			44		

Table 6. Overall proportional time spent within given depth intervals for each of the years

	Dwelling within Depth Interval - Proportional (%)								
Depth Interval	**1996**	**1997**	**1998**	**1999**	**2004**	**2006**	**2007**	**2008**	**Overall mean**
0-5 m	85.44	78.22	80.37	72.21	81.57	88.58	88.98	87.68	81.49
5.1-10 m	12.54	19.31	17.64	25.37	17.66	9.33	10.57	9.03	16.34
10.1-15 m	1.45	2.22	1.83	2.19	0.56	1.64	0.45	1.67	1.75
15.1-20 m	0.43	0.22	0.16	0.21	0.09	0.31		0.95	0.32
20.1-25 m	0.07	0.03		0.01	0.03	0.10		0.40	0.06
25.1-30 m	0.02			0.01	0.07			0.17	0.02
30.1-35 m	0.02				0.02			0.07	0.01
35.1-40 m								0.03	0.00
40.1-45m	0.02								0.01
45.1-50 m	0.01					0.03			0.01

Table 7.

Mean depth of sea trout within 5 m depth intervals, given along with standard deviation for the 8 sampling years.

	Mean Depth of Fish within given Depth Interval (m)																	
	1996		1997		1998		1999		2004		2006		2007		2008			
Depth Interval	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**No fish**	**Overall mean**
0-5 m	1.7	1.21	2.3	1.26	2.4	1.31	2.5	1.26	2.7	1.05	1.8	1.12	2.0	1.22	1.7	1.05	44	2.1
5.1-10 m	6.8	1.29	6.8	1.32	6.6	1.25	6.7	1.28	6.5	1.11	6.9	1.37	6.6	1.29	6.8	1.30	44	6.8
10.1-15 m	11.7	1.36	11.8	1.26	11.5	1.20	11.6	1.24	11.5	1.25	11.6	1.24	11.3	1.18	12.1	1.39	44	11.7
15.1-20 m	16.8	1.43	16.2	1.45	16.2	0.86	16.0	0.93	17.9	1.44	16.9	1.55			17.2	1.39	32	16.6
20.1-25 m	22.0	1.69	21.3	0.28			23.5		22.5	1.33	22.2	2.04			21.9	1.33	14	22.1
25.1-30 m	26.5	0.70					26.9		27.3	1.55					27.5	1.23	7	26.9
30.1-35 m	34.3	0.70							31.8	1.20					31.9	1.63	4	32.5
35.1-40 m															38.2	0.14	2	38.2
40.1-45 m	41.5	0.98															1	41.5
45.1-50 m	46.5										45.2						2	45.9

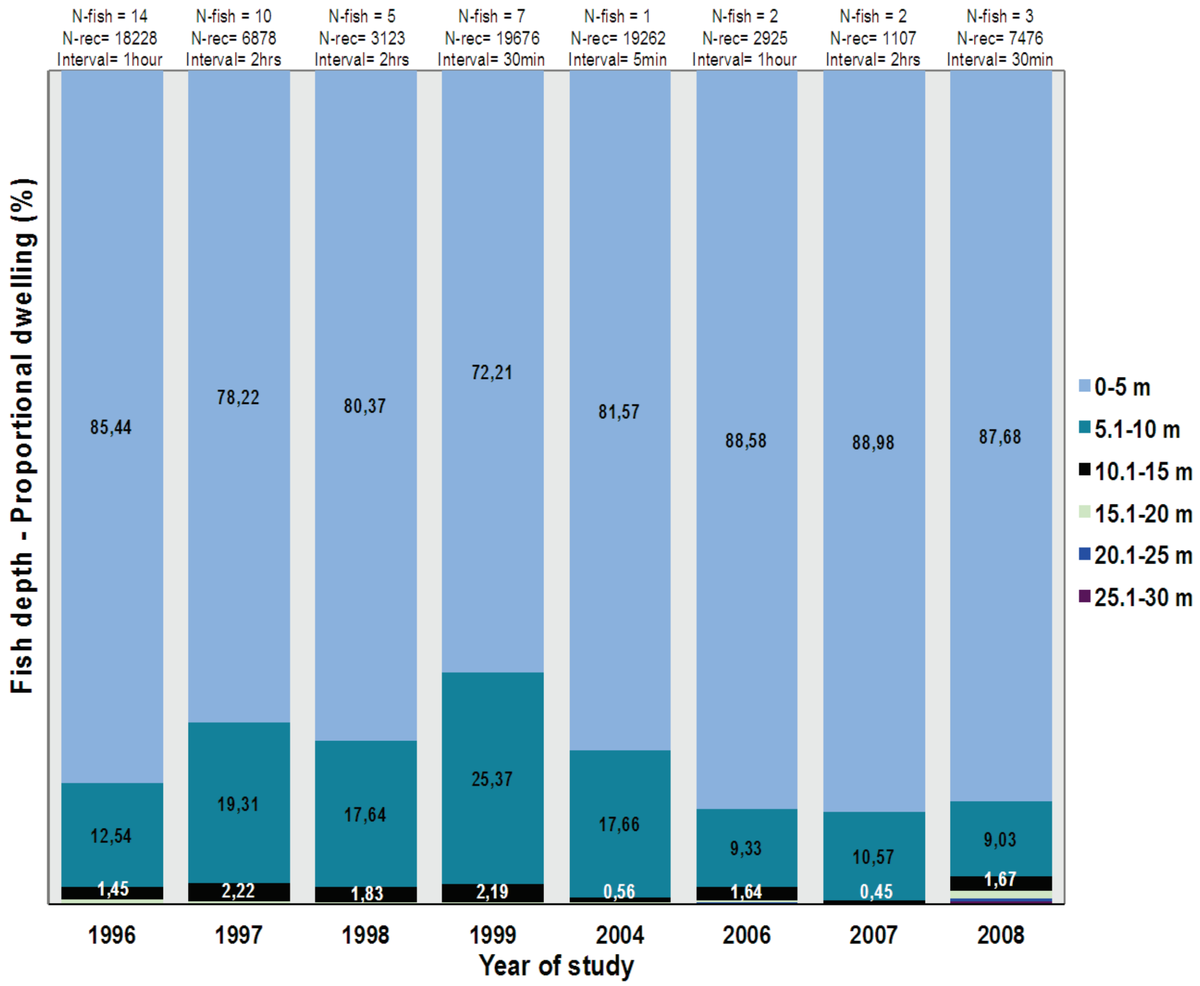


Fig. 9. The proportion of the time that the sea trout spent on average within 5 m depth intervals during their sea migration in each year. The time fish spent within the depth range is based on data for the total sea migration at the same measuring interval and is shown as the proportion of the total time at sea in the given year.

The depth distribution for the sampling years shows that the sea trout spent the majority of their time in the uppermost 5 m while migrating at sea (72-89%). The sea trout used the 5-10 m depth zone for 9-25% of their time with very little time spent in deeper sea layers. Although the sea trout were observed to move down to 47 m (Table 5) such movement into very deep layers was very rare. As given in Table 6, the time spent below 30 m was 0.1% or less for the sampling years. The time spent below 20 m acounted for 0.7% or less of their time at sea.

In Fig. 10, results based on recordings from subsampling are used to present the depth distribution in same way as in Fig. 9. The results shows the same main distribution pattern as presented in Fig. 9 although the subsampled recordings are potentially biased as the sampling was mainly very clustered in time.

Comparison of mean fish depths for a period of high frequency sampling in 2004 did not show significant difference in the mean depth observed between the 5sec-2hours sampling intervals, although the variation increased slightly for the coarser sampling periods (Fig. 11). The results partly reflected the uniformity of the depth the sea trout were utilizing.

The results on the sea trout swimming depth at sea (Figs. 8-10), as well as the results from comparison of mean depth of individuals (Figs. 12-14), results from comparison of light condition on the depth of sea trout (Figs. 15-16) and results from comparison of mean depth throughout the summer (Figs. 17-19) lead to the same conclusion, namely that the great majority of the sea trout are feeding very close to the sea surface and that seasonal and circumstantial environmental differences during their main sea migration period did not change this behaviour. The feeding grounds are mostly close to shore. Although the sea trout were observed to stay close to surface most of the time, this could at times encompass feeding close to sea bottom, if they are in shallow water.

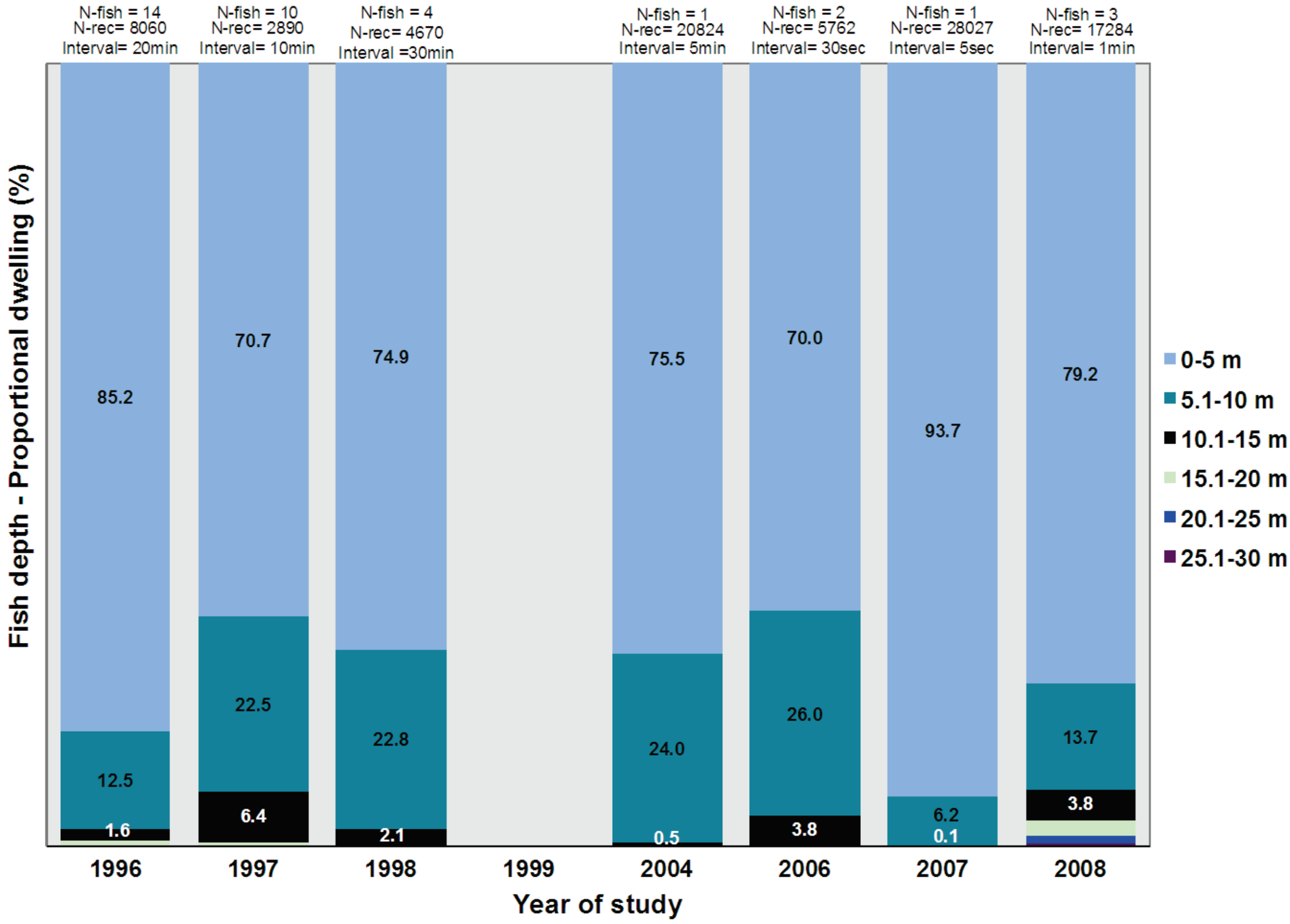


Fig. 10. The time that the sea trout spent at average within 5 m depth intervals during their sea migration for given years. The time fish spent within depth range is based on data sampled with denser measurement during the subsampling period during the sea migration. For each year the measuring interval is the same. The time spent within the given depth range is shown as a proportion of the total time spent at sea in the given year.

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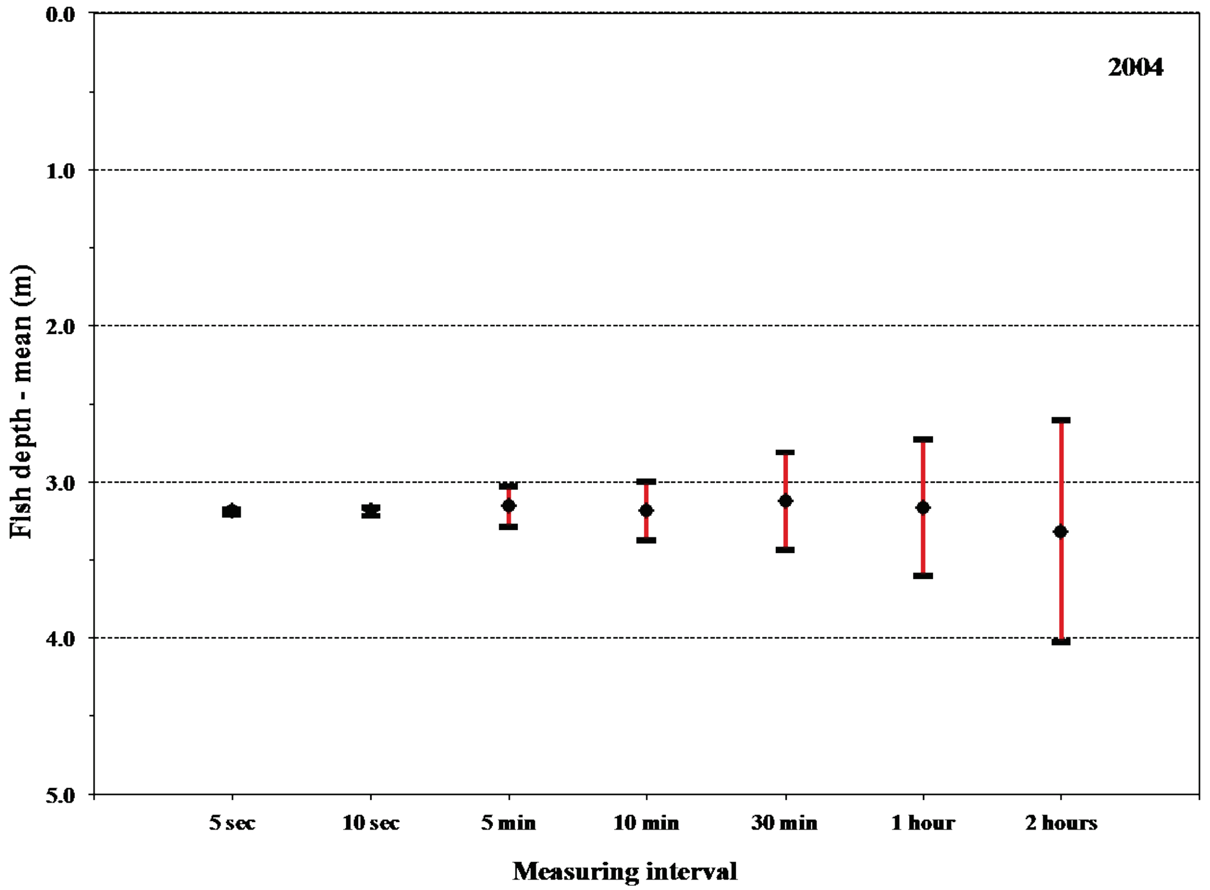
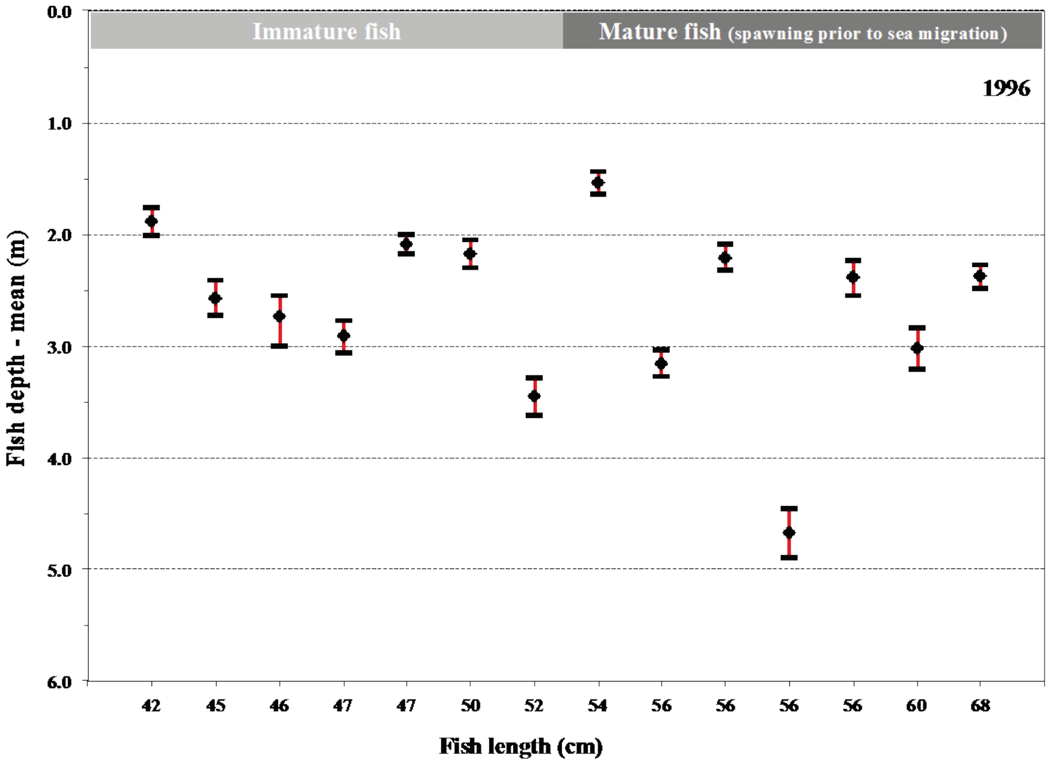
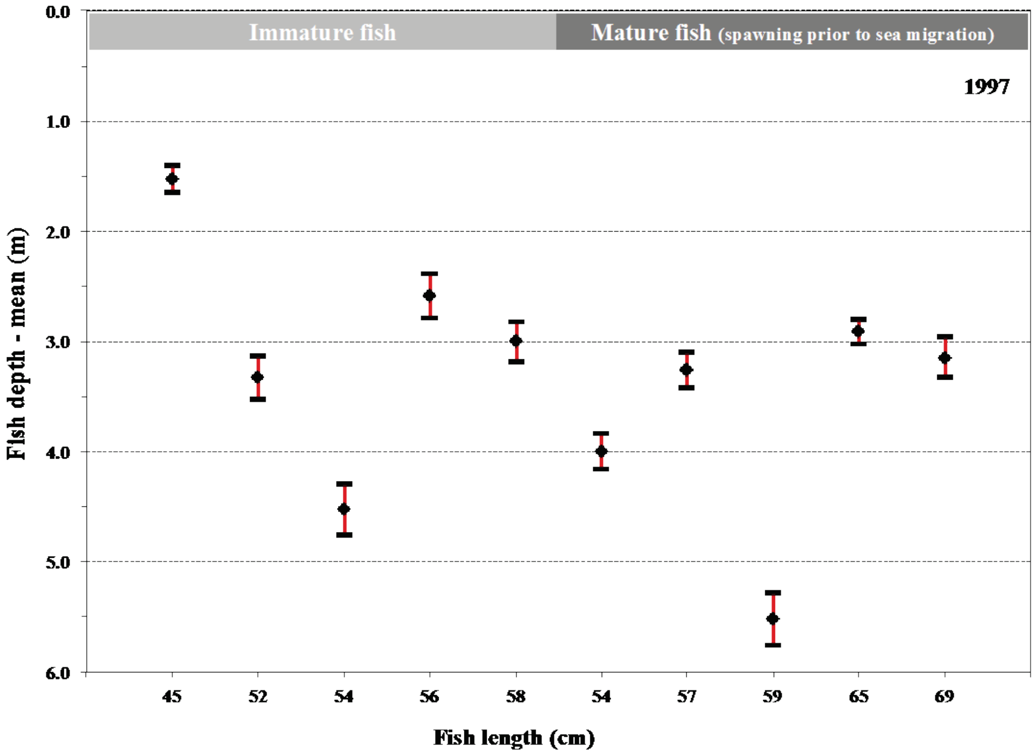


Fig. 11 . Mean values of fish depth of fish no. 37 with 95% confidence limits. The mean values are based on 7 different sampling rates in order to compare the effect that sampling rates have on the observed results.

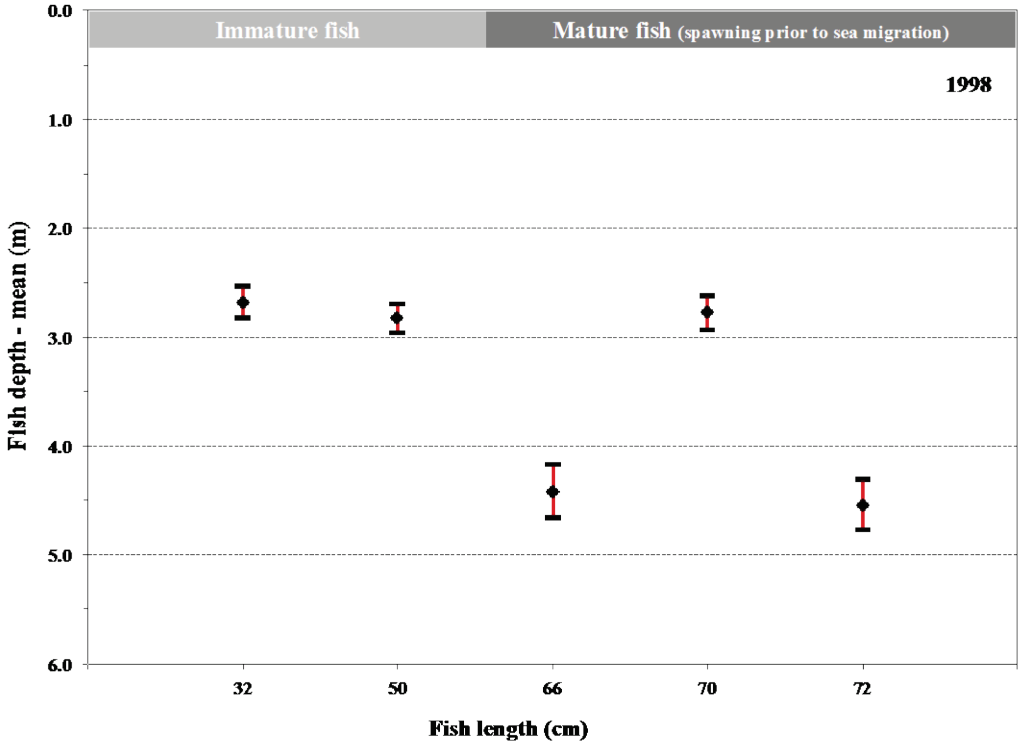


A.

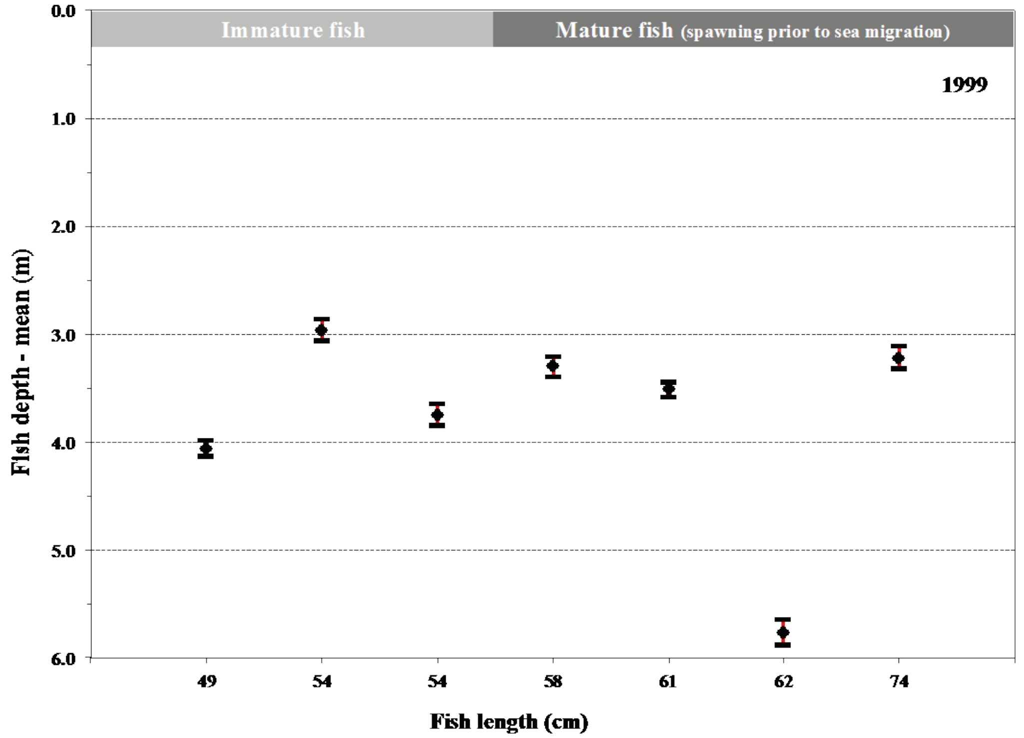


B.

Fig. 12. Mean values with 95% confidence limits of the depth of individual fish (length at tagging given) during their sea migration in 1996 (**A**) and in 1997 (**B**). Maturation status of the fish at tagging before their sea migration is shown for comparison.



A.



B.

Fig. 13. Mean values with 95% confidence limits of the depth of individual fish (length at tagging given) during their sea migration in 1998 (**A**) and in 1999 (**B**). Maturation status of the fish at tagging before their sea migration is shown for comparison.

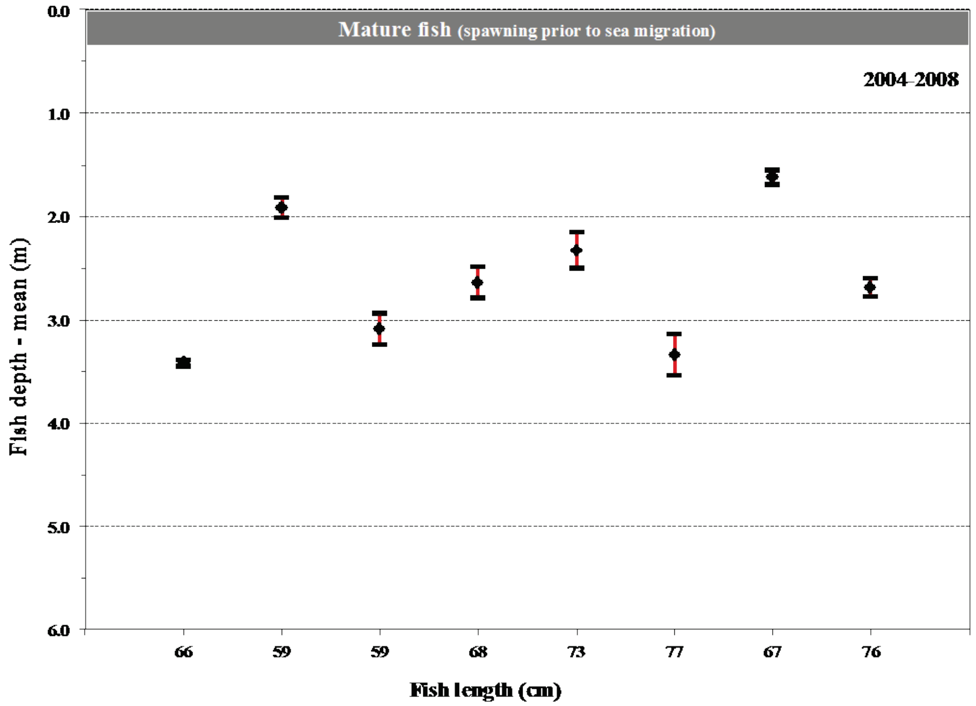


Fig. 14. Mean values with 95% confidence limits of the depth of individual fish (length at tagging given) during their sea migration in 2004-2008. Maturation status of the fish at tagging before their sea migration is shown for comparison.

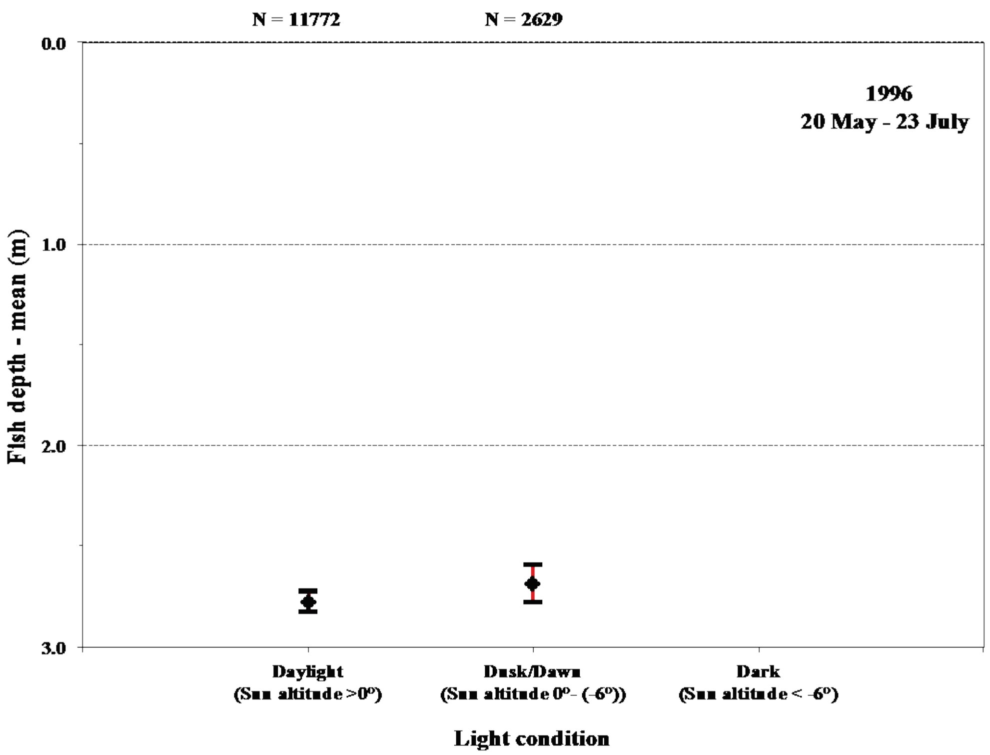


Fig. 15. Mean values with 95% confidence limits of the depth of sea trout during sea migration in 1996 during the summer period when darkness is not involved.

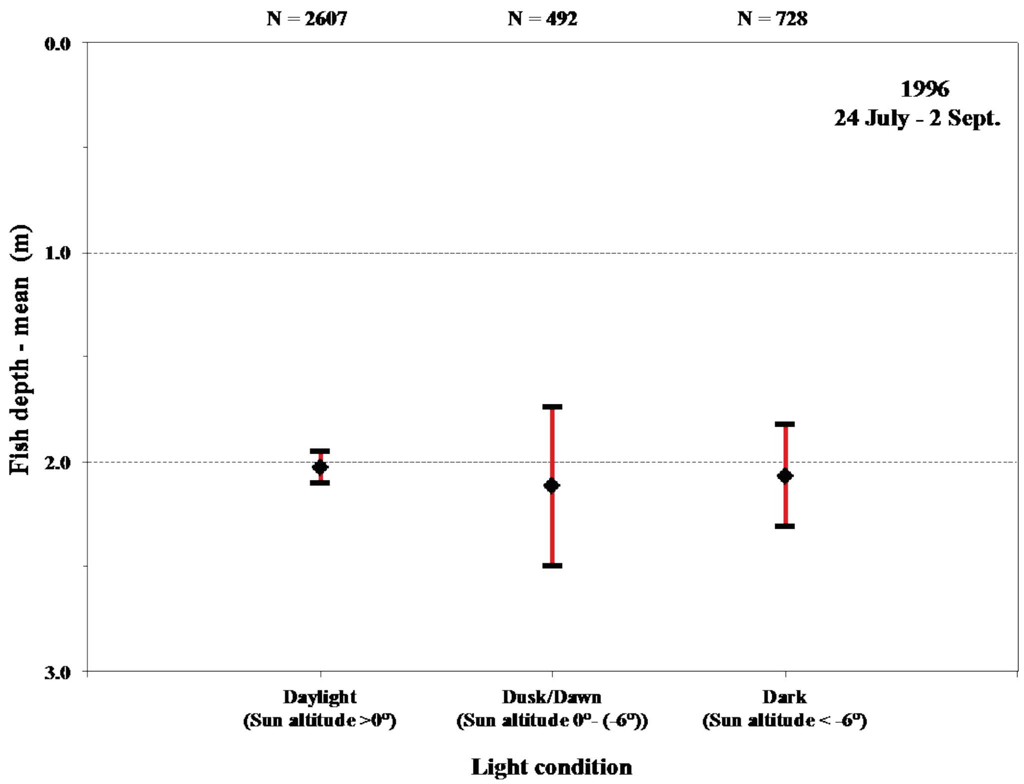


Fig. 16. Mean values with 95% confidence limits of the depth of sea trout during sea migration in 1996 during the late summer period when hours of darkness are involved.

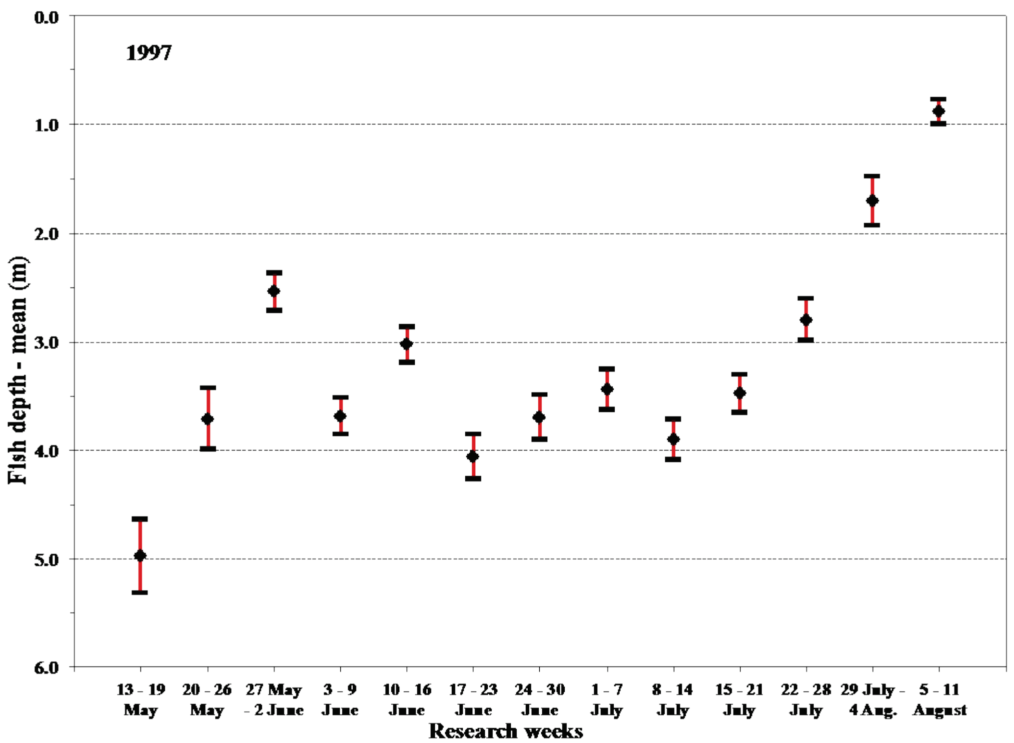


Fig. 17. Mean values with 95% confidence limits of the overall fish depth recorded by sea trout during sea migration in 1997 in each research week.

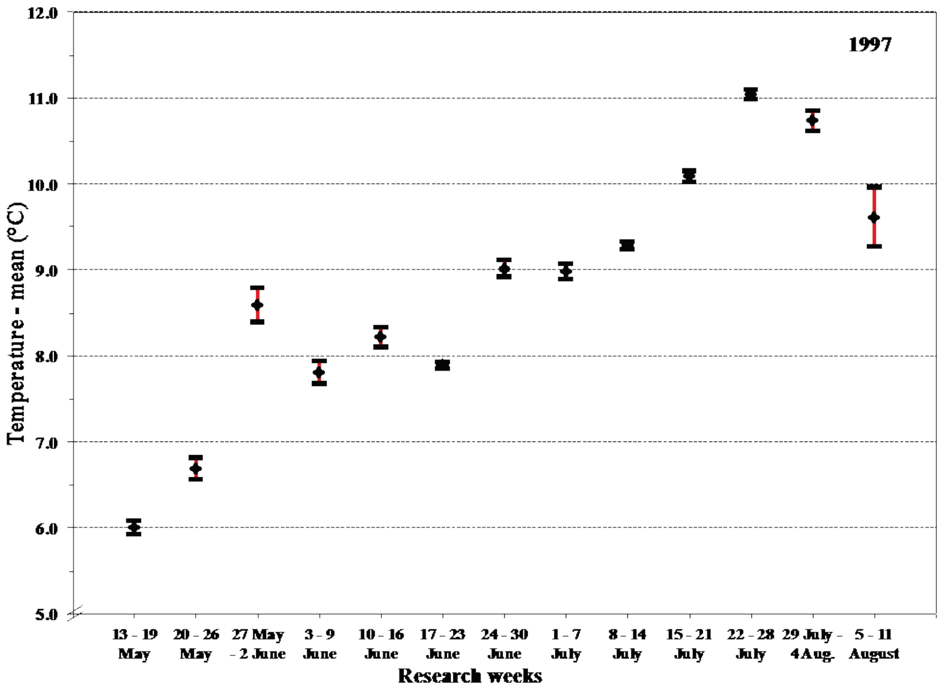


Fig. 18. Mean values with 95% confidence limits of the overall temperature experienced by sea trout during sea migration in 1997 in each research week.

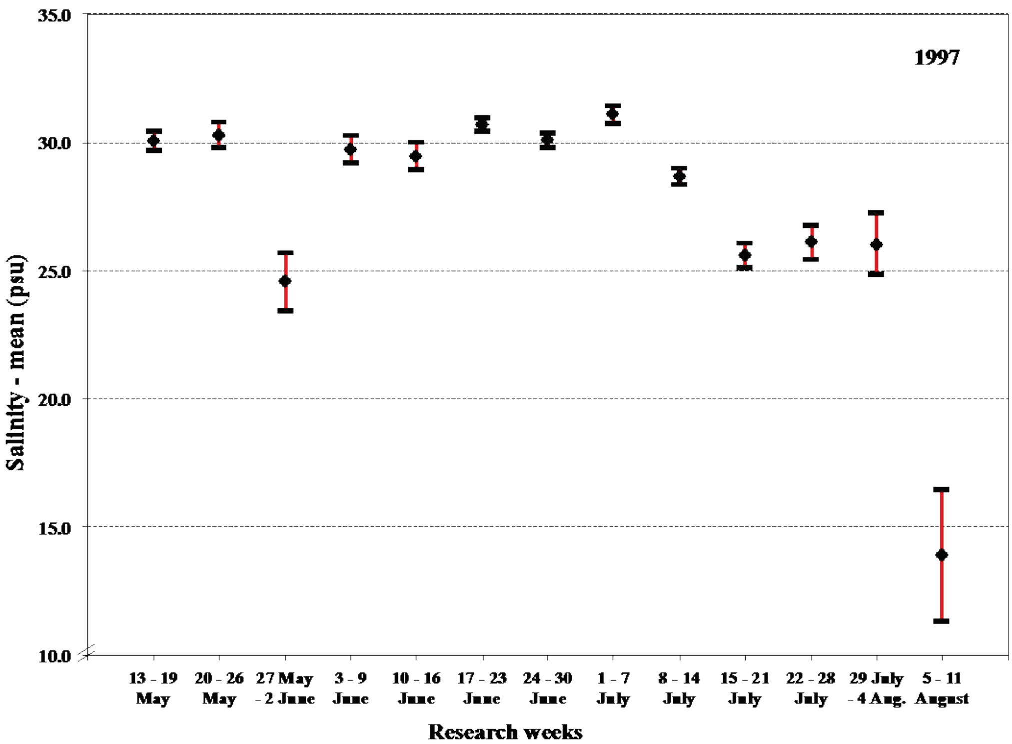


Fig. 19. Mean values with 95% confidence limits of the overall salinity experienced by sea trout during sea migration in 1997 in each research week.

The deviation in the overall mean temperature and salinity experienced by the sea trout during 20-26 May 1997 represents a temporary stay in brackish water (Fig. 18 and 19). This could be very close to the shore or in estuarine areas but could also partly be explained by proportion of fish starting their sea migration in this period. The similar deviation during 5-11 August is presumably the result of fish in the estuary finishing their sea migration.

When the overall mean values for temperature and especially salinity within each of the 5 m depth intervals are compared it is apparent that these values for the uppermost 5 m differ significantly from the other depth intervals (Figs. 20 and 21). The low salinity shows that during sampling in 1997 the sea trout were experiencing relatively low salinity during the majority of their sea migration. This again points towards their shoreline orientation when feeding at sea.

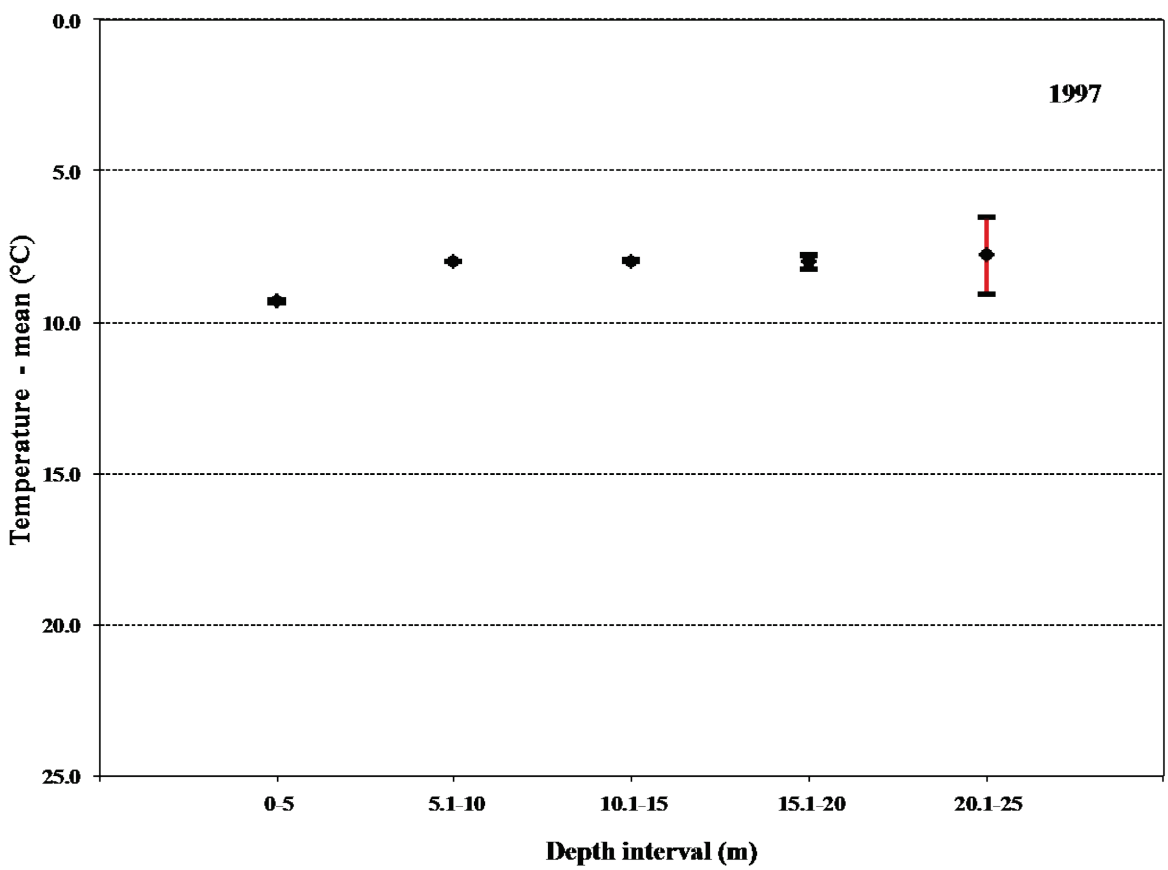


Fig. 20. Mean values with 95% confidence limits of the temperature experienced during sea migration of sea trout in 1997 in the 5 m depth intervals.

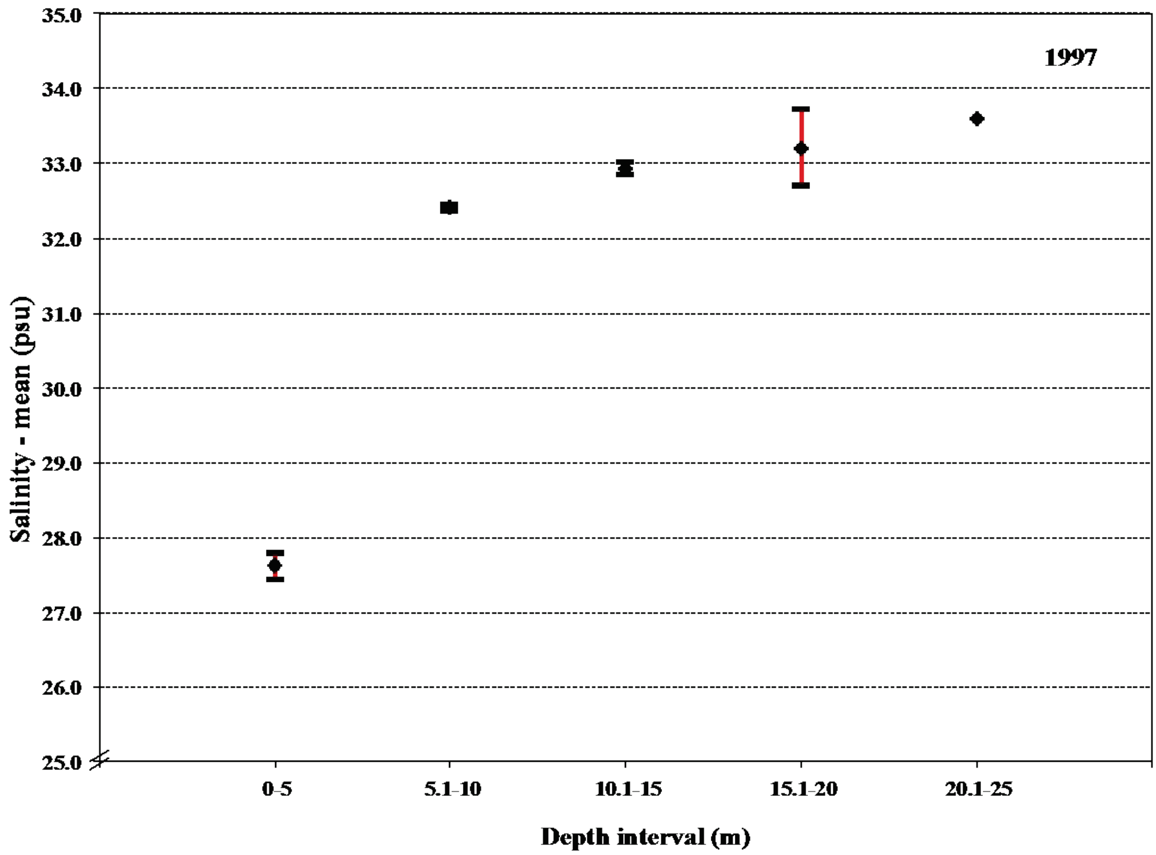


Fig. 21. Mean values with 95% confidence limits of the salinity experienced during sea migration of sea trout in 1997 in the 5 m depth intervals.

5. Other available information on sea trout swimming depth

Four other studies document the swimming depth of sea trout during their migration in sea, and all show results consistent with the present study (Sturlaugsson and Johannsson 1996; Rikardsen *et al* 2007; Hantke *et al* 2011 and Davidsen *et al* 2014).

Studies in coastal waters of Iceland in 1995 showed that during the sea migration sea trout tagged with data storage tags spent vast majority of their time in coastal waters within the uppermost 5 m (Sturlaugsson and Johannsson 1996).

Rikardsen *et al* (2007) tagged eight sea trout with data storage tags in Alta Fjord in northern Norway in 2002. The fish were recaptured 1-40 days later. The sea trout spent more than 50% of their time between 1 and 2 m depth and more than 90% of their time in water no deeper than 3 m from the water surface. However, deeper dives (to a maximum of 28 m) were also recorded. These deep dives were most frequently performed at the end of the sea migration.

Hantke *et al* (2011) give swimming depth information for tagged sea trout in coastal waters in northern Germany. They include in their abstract that "The majority of the tagged sea trouts (64%) migrated at the uppermost water level at about 1.5 m. Common behaviour of sea trouts was occasional deep dives up to 13 m water depth. Two patterns of vertical movements have been observed, rapid dives down from the surface layers or continuous movements in the upper layers."

Davidsen *et al* (2014) give swimming depth information for tagged sea trout in a fjord in Central Norway. They include a summary that "Average swimming depth in the period from April to September (1.87 m) varied significantly among habitats. In littoral (2.11 m) and cliff habitats (2.53 m) the average swimming depth was significantly deeper than in pelagic areas (1.26 m). The average swimming depth was significantly deeper during day (1.98 m) than night (1.28 m). The sea trout had a progressively deeper swimming pattern from April towards late summer, which was positively correlated with water temperature, suggesting that the sea trout actively regulated its internal body temperature."

6. Conclusion

The work presented here, based on the DST data from sea migration of sea trout, makes available in a suitable format for marine renewables risk assessment detailed and useful new information on the swimming depths of sea trout.

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